



US Army Corps
of Engineers®

**Bluestone Dam
Workshop on Rock Anchors
September 17-18, 2002**

**Geological Controls on
Overall Stability and
Interface Design**

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Schnabel
FOUNDATION COMPANY

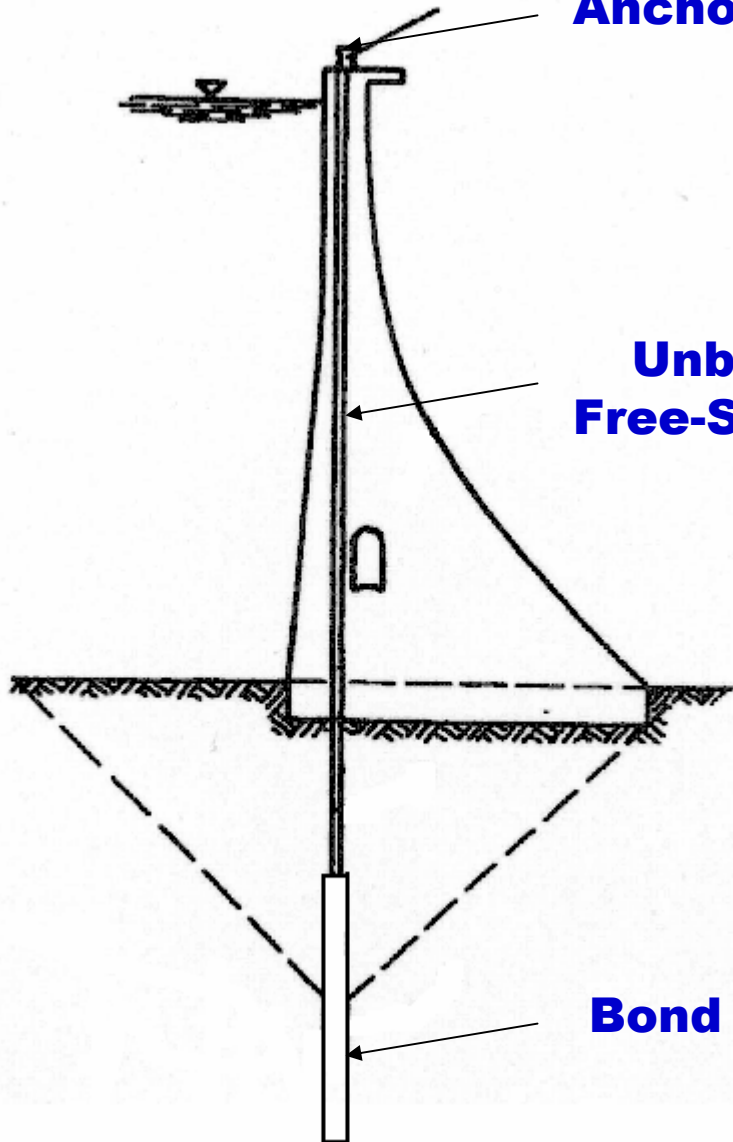
Basic Definitions

**Tiedown or
Ground Anchor**

Anchorage

**Unbonded Length
Free-Stressing Length**

Bond Length



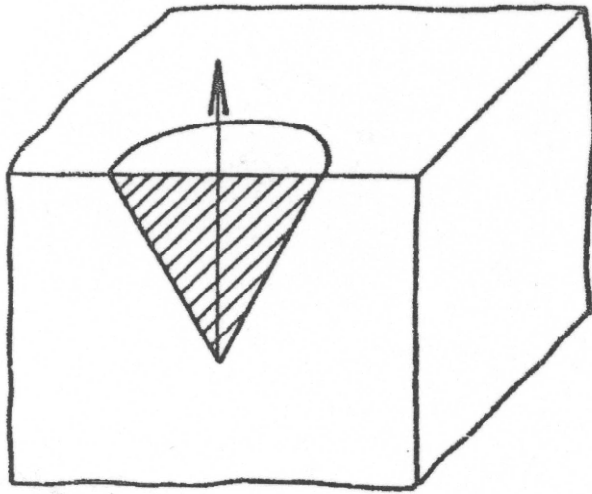
DAM TIEDOWNS Must

- **Develop Required Pullout Resistance**
- **Anchored in a Stable Rock Mass**

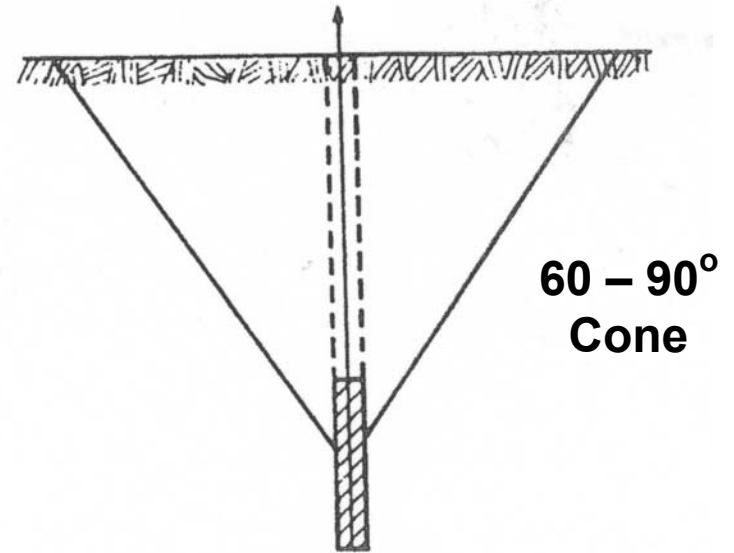
Potential Failure Mechanism

- **Failure of the ROCK MASS**
- **Failure of the GROUT/TENDON interface**
- **Failure of the ROCK/GROUT interface**

Rock Mass Stability Single Tiedown



Inverter Cone



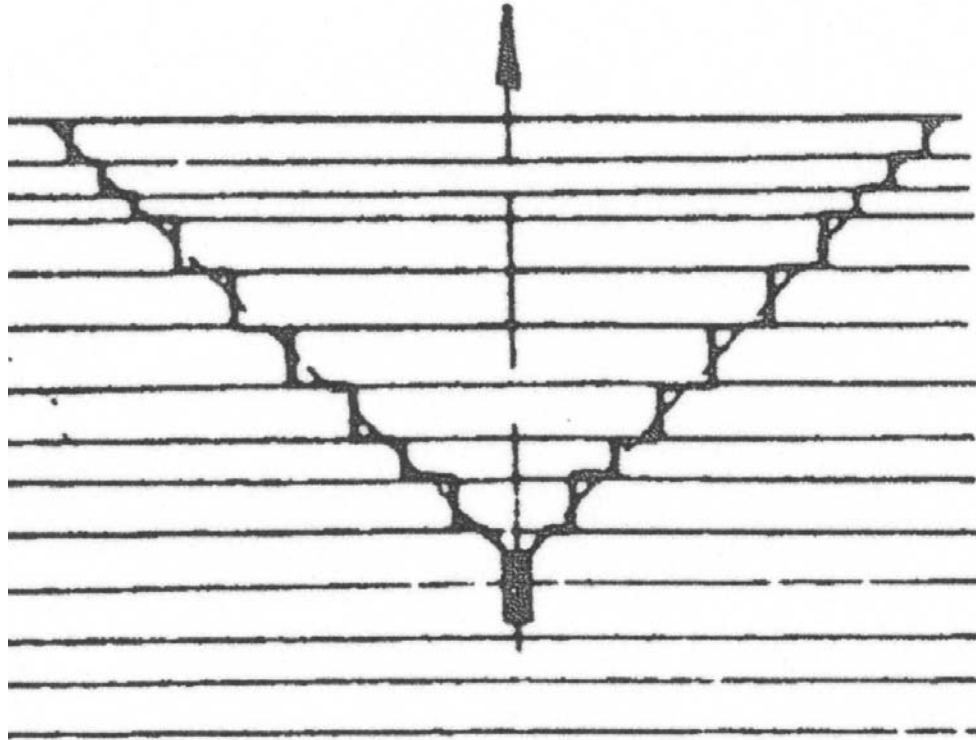
Apex at Center of the Bond Length

Tiedown Uplift Capacity = Effective Weight of Cone

Effective Unit Weight = Total Unit Weight – Water Pressure

Usually Ignore the Shear Resistance Along the Cone

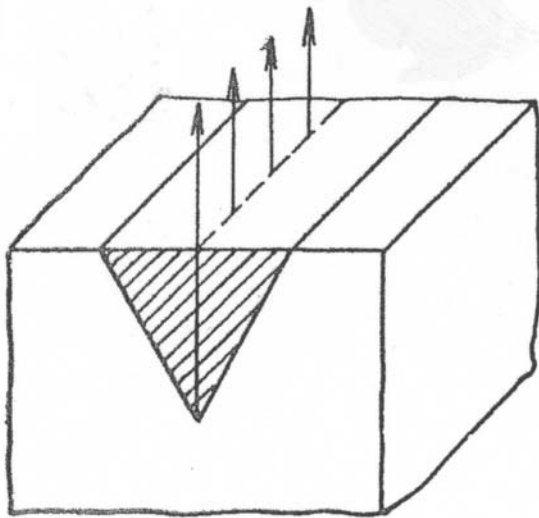
Rock Mass Stability Single Tiedown



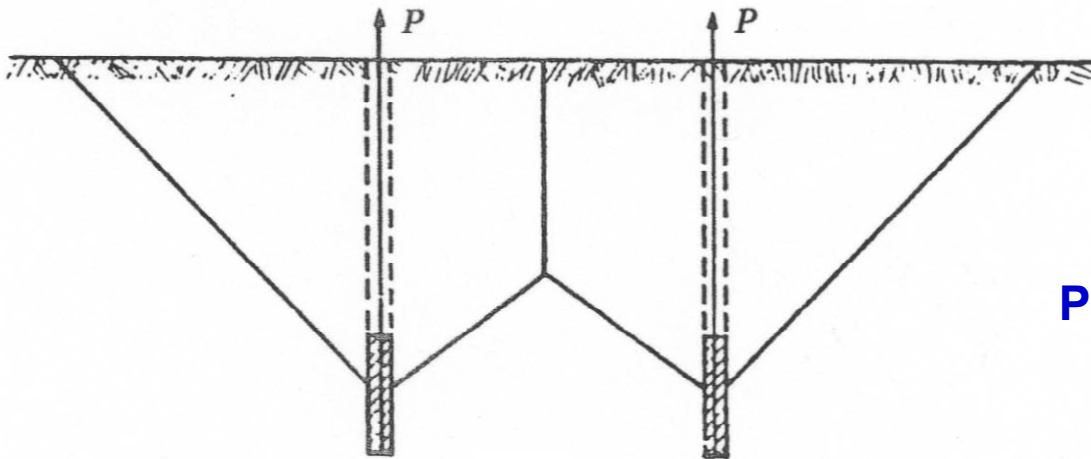
Fractured and Weak Rock

**Discontinuities
Define Shape of
Rock Mass**

Rock Mass Stability Group Effect

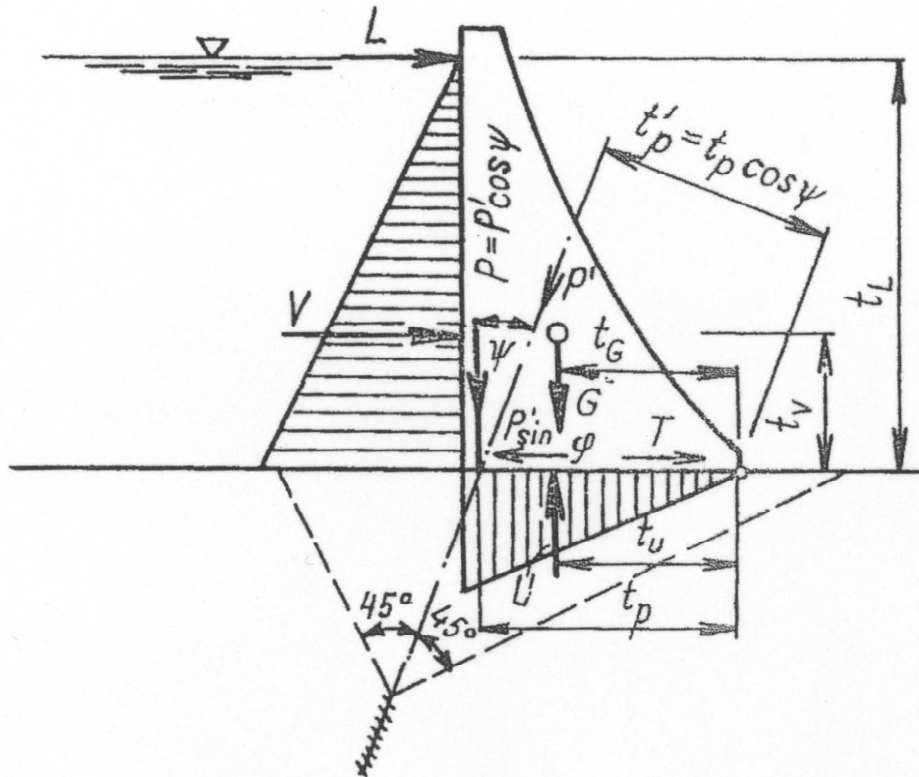


Single Row



Parallel Rows

Rock Mass Stability



Shape of the Rock Wedge when Tiedown Installed at an Angle

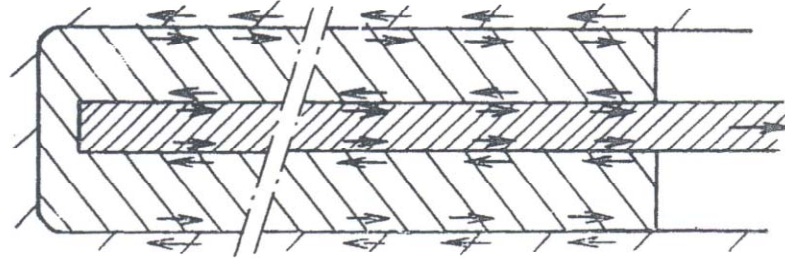
Rock Mass Stability

- **Attempt to locate the tiedowns to achieve maximum effectiveness in stabilizing the dam.**
- **Penstocks, galleries, embedments, and drainage systems will constrain anchor location.**

Rock Mass Stability

- **Start the bond length at least 10' below the bottom of the dam**
- **Increase the size of the rock mass by lengthening tiedowns**
- **Reduce interaction by:
lengthening alternate tiedowns,
changing angles and multiple
rows**
- **FS 2 to 3**

Grout/Tendon Bond



Three Components of Grout/Tendon Bond

- **Adhesion**
- **Friction**
- **Mechanical Interlock**

Adhesion

**Physical Bond between the
Surface of the Steel and the Grout**

**Adhesion is destroyed with
small relative movements
between the tendon and
the grout**

Friction

Depends on the Lateral Confining Stress and the Roughness of the Tendon and the Amount of Slip

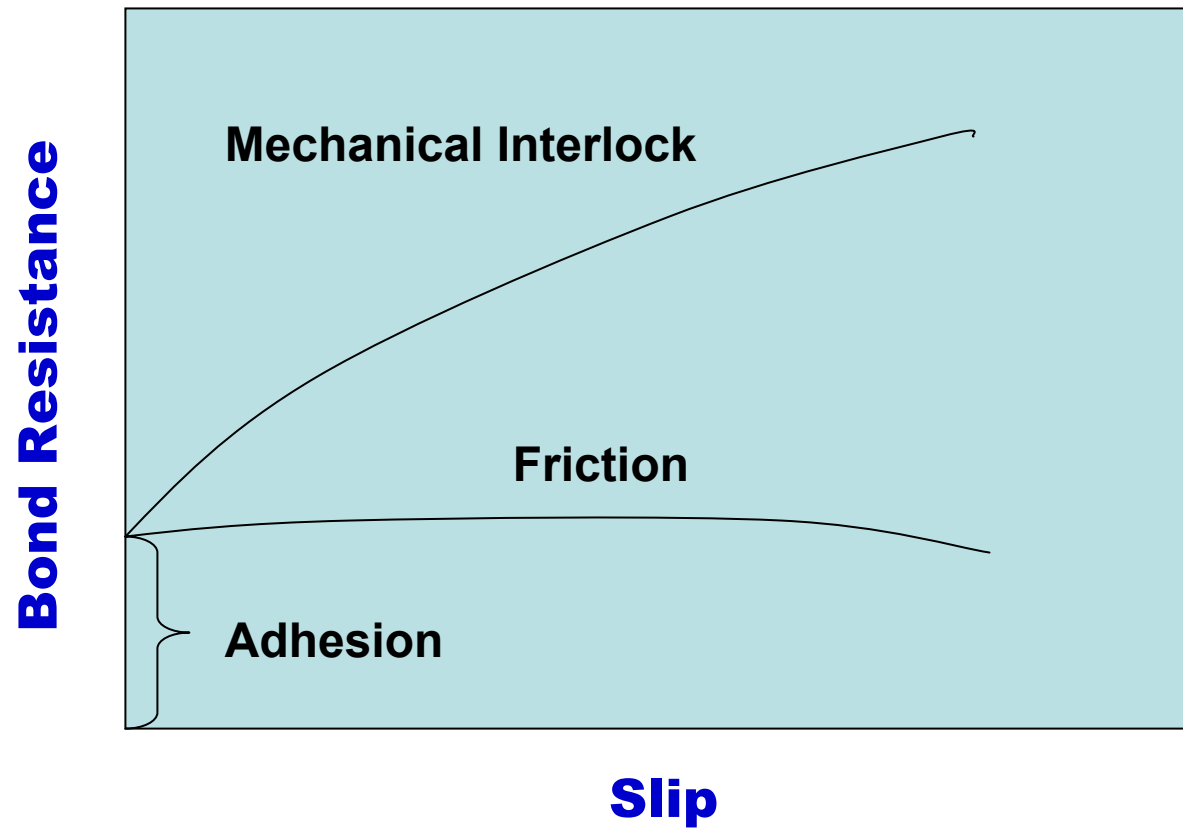
Mechanical Interlock

Mobilization of Grout Shear Strength by Major Tendon Irregularities.

Ribs on bars

Twists and Waves on Multi-Strand Tendons

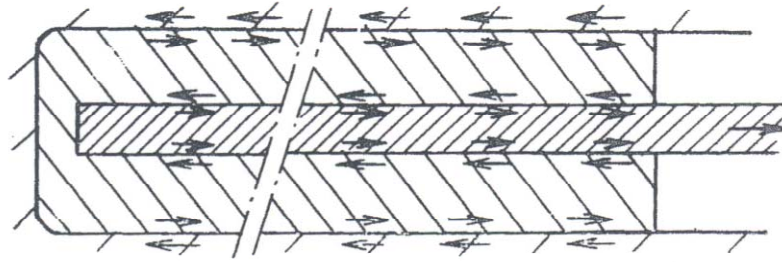
Components of Grout/Tendon Bond



GROUT/TENDON BOND

- **Grout/Tendon Bond is not Critical, Grout/Rock Bond Controls**
- **PTI Recommends Tendon Area \leq 15% of Total Grout Area**
- **Strand Satisfy ASTM A 981-98**

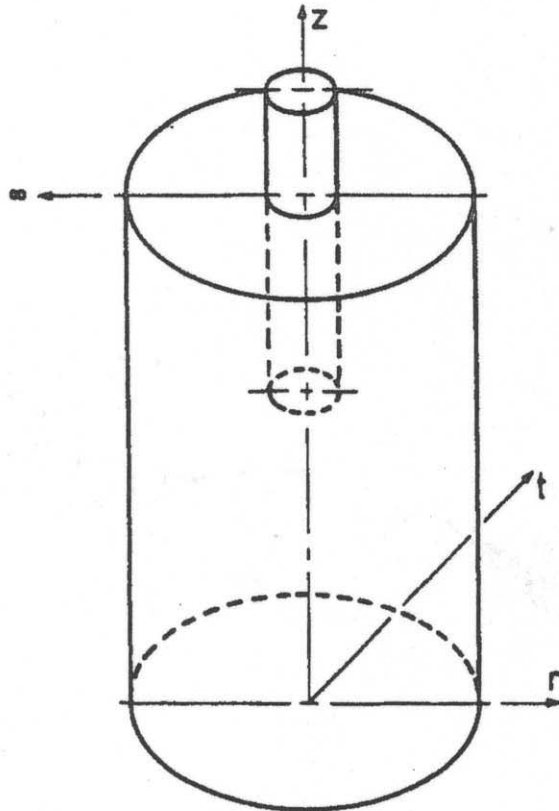
Grout/Rock Bond



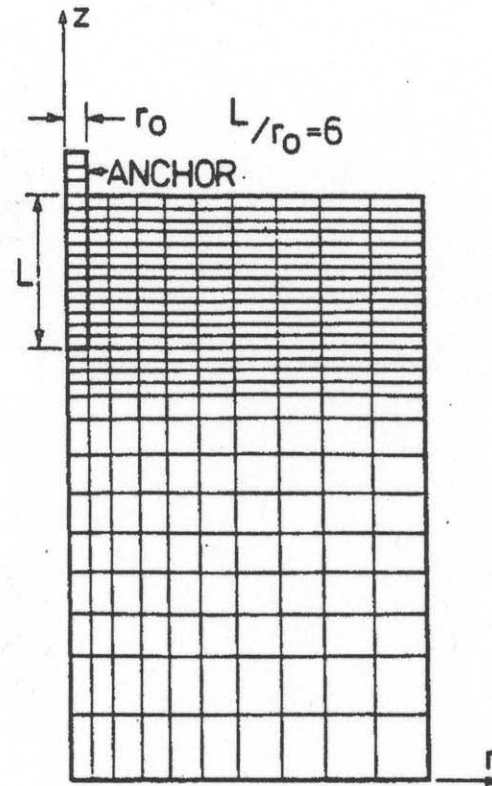
- **Strength of the Rock**
- **Discontinuities in the Rock Mass**
- **Drilling Method and Hole Cleaning Method**
- **Grout w/c Ratio**
- **Grouting Method – Tremie vs. Pressure**
- **Delay in Grouting**

Grout/Rock Bond

FE Study

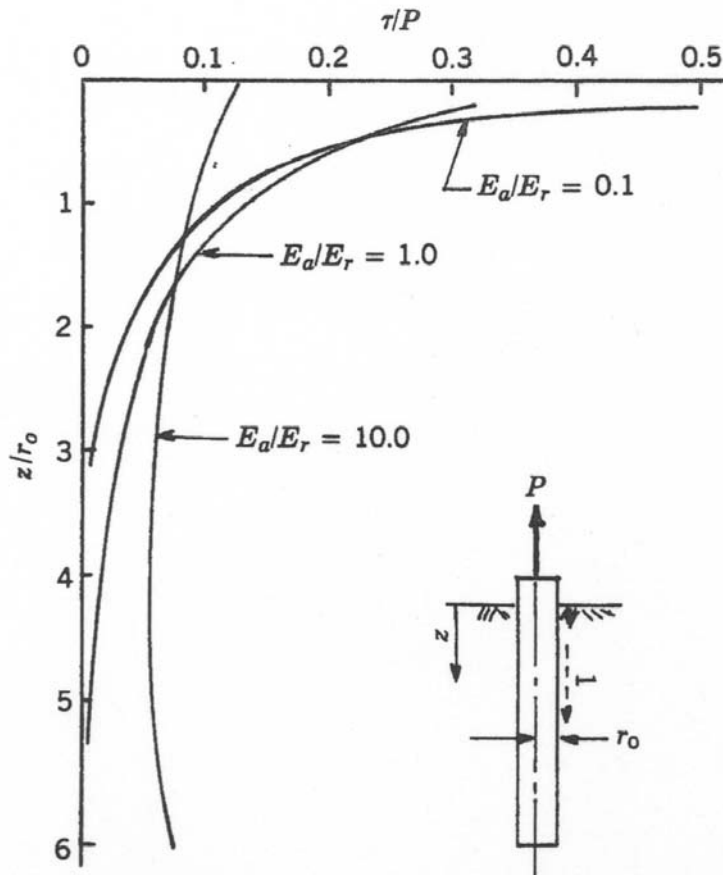


Definitions



FE Model

Grout/Rock Bond



$$E_s = 29,700 \text{ ksi}$$

$$E_g = 3,500 \text{ ksi}$$

$$\text{UCS rock} = 10,000 \text{ psi}$$

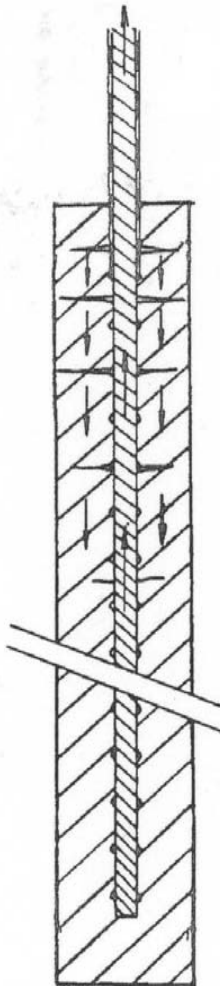
$$E_r = 3,500 \text{ ksi}$$

$$E_a = E_s$$

$$E_a/E_r = 8.5$$

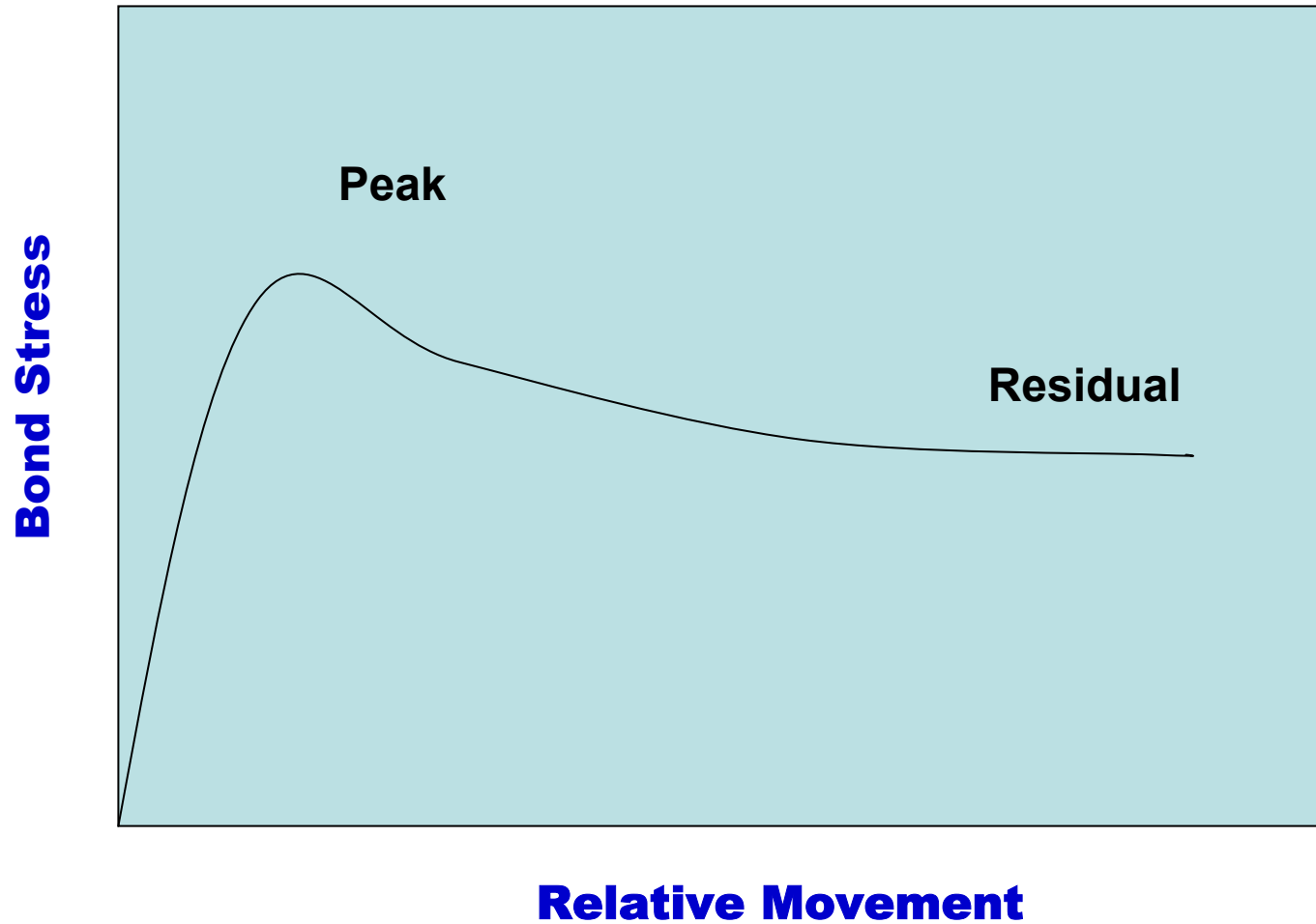
$$E_a = E_g$$

$$E_a/E_r = 1$$



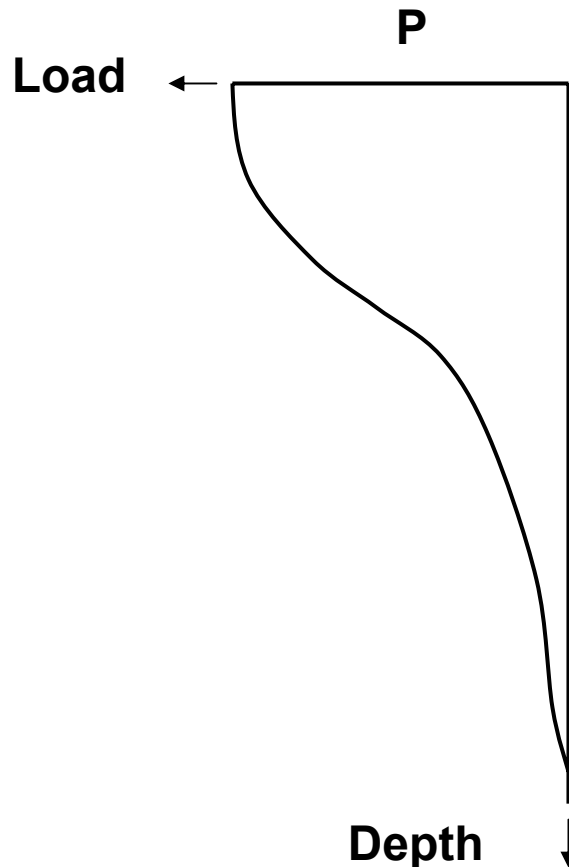
Results of Coates and Yu's FE Study

Grout/Rock Bond



Grout/Rock Bond

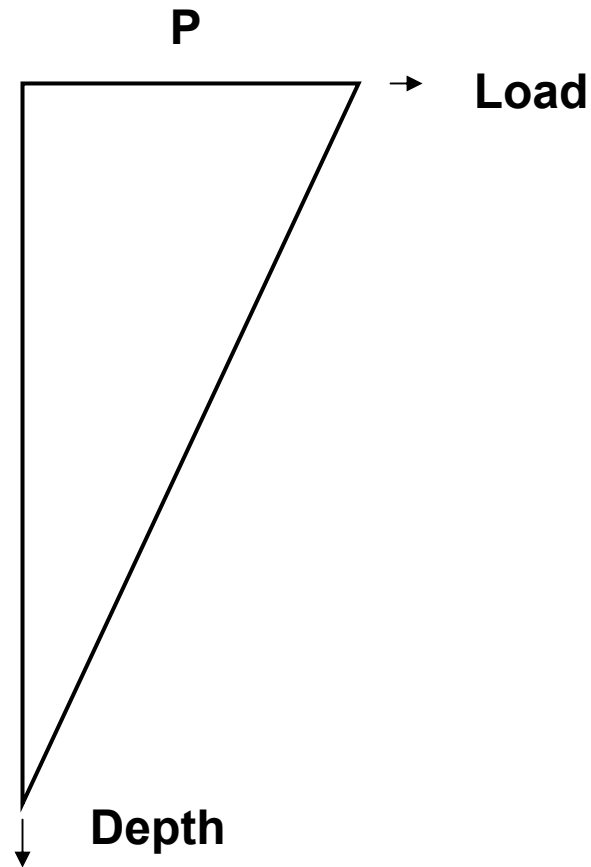
Actual Distribution of Load
Along The Bond Length



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Assumed Distribution of Load
Along The Bond Length –
Uniform Grout/Rock Bond Stress



Grout/Rock Bond

Depends Upon Strength of the Rock

Rock	Average Ult. Rock/Grout Bond (psi)
Granite & Basalt	250 - 450
Dolomitic Limestone	200 – 300
Soft Limestone	150 – 200
Slates & Hard Shales	120 – 200
Soft Shales	30 – 120
Sandstones	120 – 250
Weathered Sandstones	100 – 120
Chalk	30 – 155
Weathered Marl	25 – 35
Concrete	200 - 400

$$\text{Allowable bond stress} = \frac{\text{Ult. Bond Stress}}{2 \text{ or } 3}$$

Grout/Rock Bond

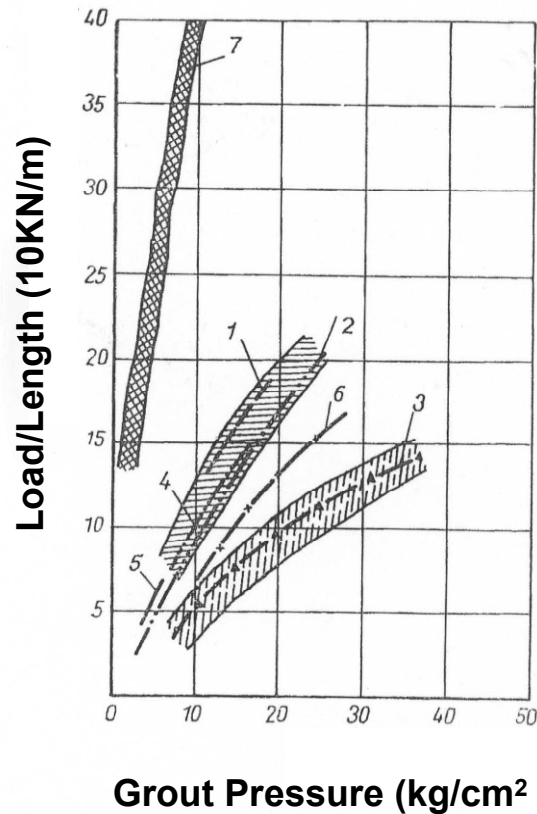
Discontinuities in the Rock Mass Effect E_r – Bond Stress Distribution and Magnitude of Bond Stress

Drilling Method and Hole Cleaning Method – High Bond Stress in a Clean Hole

Grout w/c Ratio → Shrinkage and Strength → Rock/Grout Bond Stress and Grout Bleed

Grout/Rock Bond

Grouting Method – Tremie vs. Pressure



- 1- Medium Brussel's sands
- 2- Marly Limestone
- 3- Marls
- 4- Seine fluvial deposits
- 5- Clayey gravels and sands
- 6- Soft Cretaceous sediments
- 7- Hard Limestone

Grout/Rock Bond

Delay in Grouting → Allows Some Rocks to Degrade → Lowers Bond

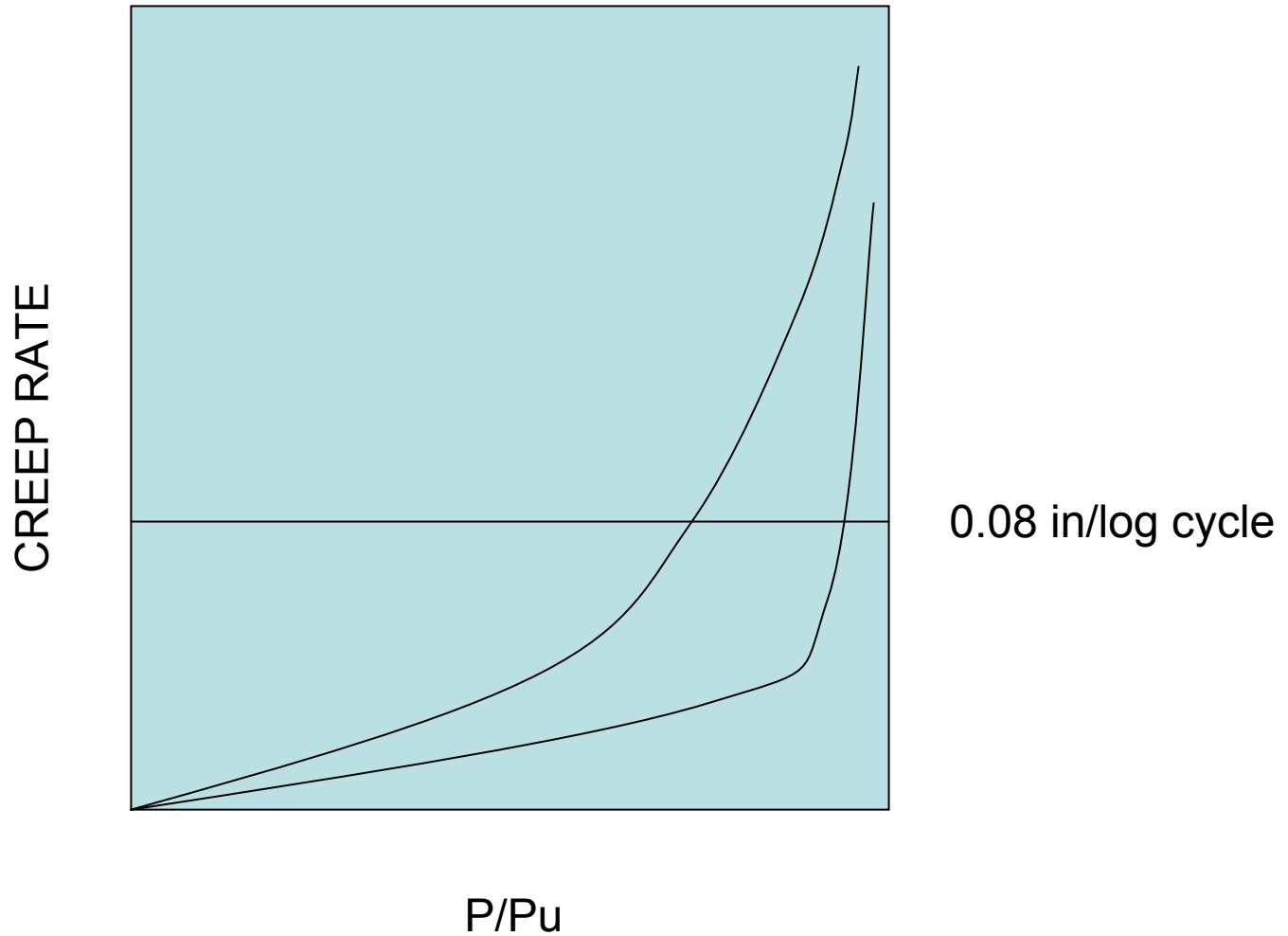
TIME DEPENDENT BEHAVIOR

- **Rock**
- **Material**

TYPES of TIME DEPENDENT BEHAVIOR

- **Creep**
- **Relaxation**

CREEP BEHAVIOR



When Has Creep Been Observed

- **Clay Shales and Poor Hole Cleaning**
- **Strands w/ Drawing Lub.**
- **Epoxy Coated Strand**

Concluding Remarks

- **Good Rock = High Bond Stress and Life is Good**
- **Weak Rock = Lower Bond Stress and More Care Required**
- **Poor Quality, Weak Rocks Require Careful Exploration, Water Pressure Measurements, Water Pressure Testing, Consolidation Grouting and Test Anchors**